Undersea Distributed Networked System: *An Enabling Power and Communications Infrastructure Technology*

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Monitoring the ocean, whether for defense, port security or oceanographic and climatological purposes is becoming increasingly important. As a result there is need for a flexible, reliable, economical and easy way to deploy infrastructure for providing power and communication pathways to sensor arrays. In this paper we will describe three key subsystems which, when combined with standard undersea telecom cable and commercially available connectors, create a complete infrastructure to support an undersea array of sensors. A generic depiction of a typical deployment showing all the subsystems and components is shown here in Figure 1.

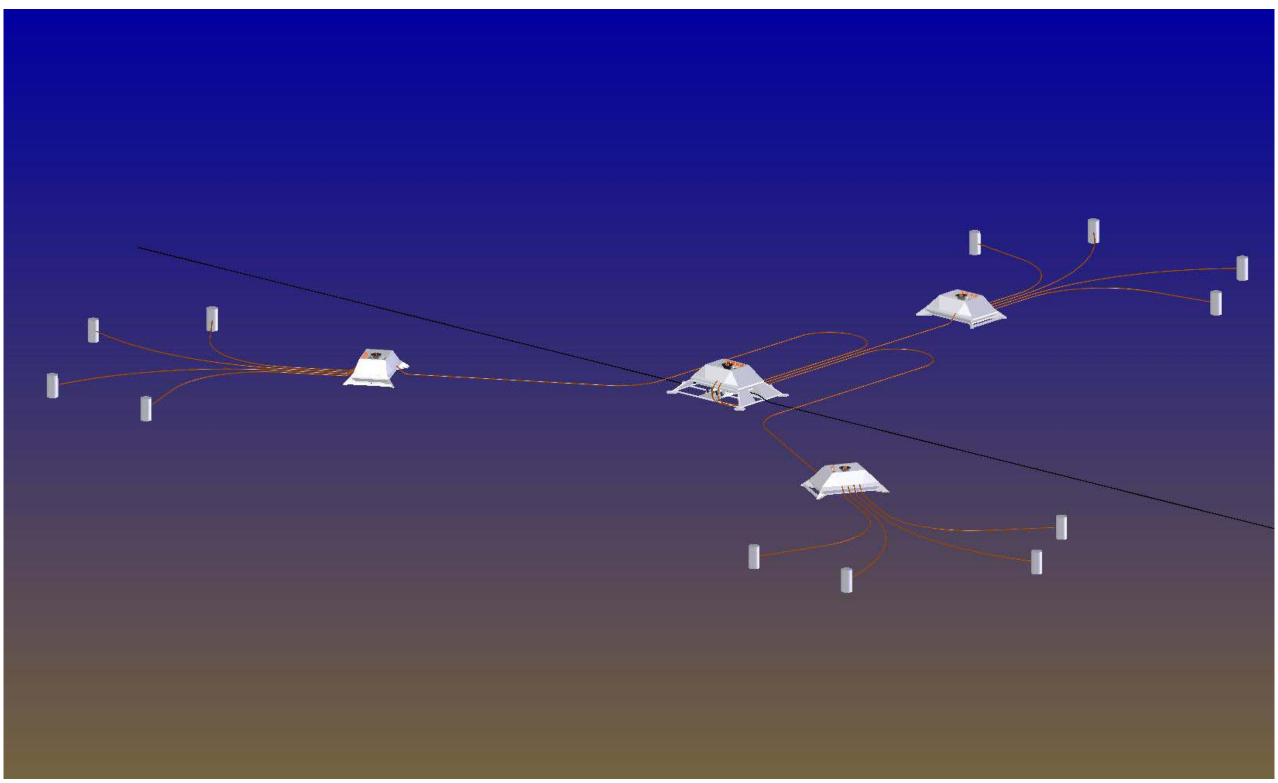

Figure 1

This is a conceptual view of part of a Gateway deployment. It shows a single Hub Node with three connecting Sensor Nodes each Sensor Nodes supporting 4 sensors. The Sensor Nodes can be several km from the Hub node. Individual sensors will typically be deployed less than 100m from the Sensor node.

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The design goal of the Gateway System was to use existing commercial off the shelf (COTS) parts in an innovative way to make a basic set of standardized subsystem modules which can be assembled into an infrastructure that will support a wide variety of oceanographic sensors and allow them to be deployed over a wide range of ocean floor regions. The gateway system is designed to handle at least 95% of the sensors available today. The design uses a standard 10kV DC power supply (PFE) used to power undersea telecommunications cables. This allows those deploying sensors to either build a new installation or to retrofit a decommissioned communications cable. This also enables several hub nodes to be distributed along the length of a cable allowing simultaneous access to disparate regions of the ocean floor. The three subsystem modules are a Hub Node, a Sensor Node and a shore station. The key components are the cables, connectors and sensors. The deployment topology is trunk and branch, with the trunk reaching at least 2000 km. It will be able to provide power and communications infrastructure for as many as 132 individual sensors. Another unique feature is that the modules will have a standard design, and support all standard interfaces needed to connect to sensors. The optical communication path will support standard telecom protocols (SONET or Ethernet). In this way we hope to have an 'open architecture' that will be easily accessible to all end users.

The trunk cable is a standard undersea telecommunications cable carrying two bi-directional fiber pairs and a low impedance (1 Ω/km or less) conductor. It is terminated at one end on land at the shore station, while the other end can be terminated at a sea ground or at another shore station. The shore station(s) will provide power and communications terminals to the trunk cable.

The Hub Nodes are placed serially along the length of the trunk cable to route power and wavelengths to the branch cables. Undersea amplifiers (repeaters) can be incorporated into the trunk cable, since the Gateway System uses constant current power feed equipment (PFE) and telecom cable for the trunk cable. This allows the reach of the trunk cable to extend to over 2000 km. Depending on the length of the trunk cable, a Gateway System installation can support up to 11 Hubs, each with three branch ports.

The Sensor Nodes connect via cable to the Hub branch ports. They function as power and communication interfaces to the actual sensors and are designed to support up to 4 sensors. The Sensor Node can be placed several km from the Hub Node. The cable connecting the Sensor and Hub Nodes has wet mate connectors. Hence a Sensor Node can be connected to, and disconnected from the Hub using a remotely operated vehicle (ROV) or a diver. This will allow for easy repair, replacement or reconfiguration of sensors.

In the following we will discuss the details of our design.

The Hub Node

The Hub Nodes are connected serially into the main trunk cable. The Hub Node will drop a fixed amount of power from the trunk cable power conductor and allow predetermined wavelengths to be added or dropped to the fiber pairs in the trunk cable. We have purposefully selected a constant current source for the land based power feed equipment (PFE) connected to the trunk cable. It is capable of putting out 1 A at up to 10 kV. This will bound the amount of power available to a single sensor array installation.

For reference in our discussion of the Hub Node we have included Figure 2 showing a functional schematic of the Hub Node and Figure 3 showing a physical representation of the Node. The Hub is separated into an electrical section and an optical section. Within the electrical section of the Hub Node, Zener diodes will produce a voltage drop from the line current flowing in the trunk cable. As shown in Figure 2, there are several diode shunt converters in series for a total voltage drop of 880 V. The power from each shunt converter is regulated by a DC/DC voltage converter which steps down the voltage from 220 V to 100 V. The outputs of the DC/DC converters are combined onto an output bus. This bus is connected to three output ports for connecting to cables that terminate the Sensor Nodes.

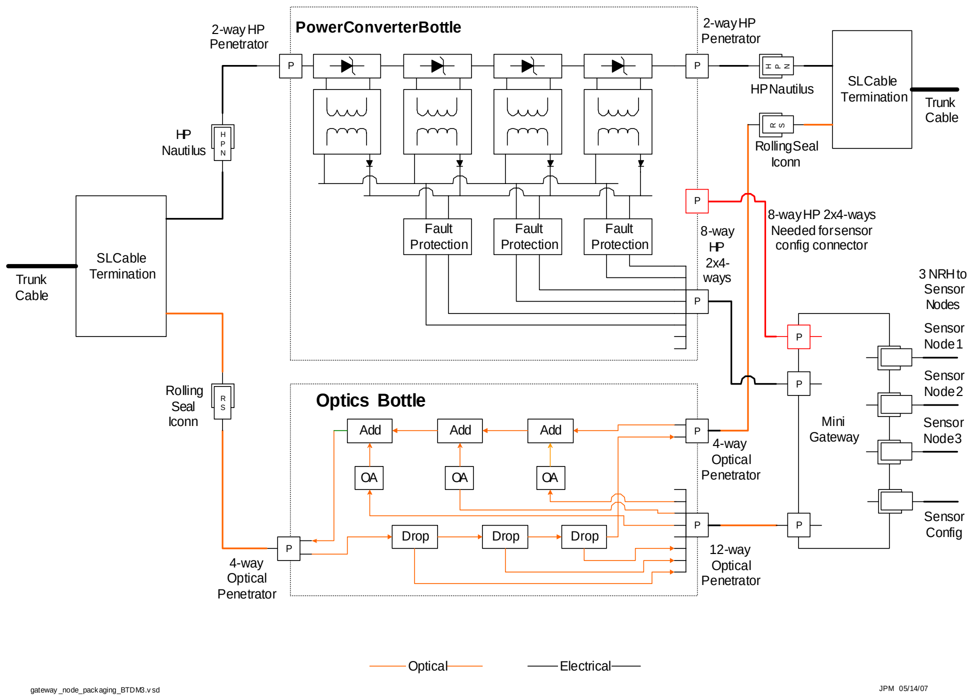

Figure 2

This figure shows s functional representation of the key components of a Hub Node. The optical components and the electrical components are put in separate housings. Connectors are used throughout this module to allow for easy installation and repair. Note, for simplicity we do not show the second fiber pair and set of add drop multiplexers.

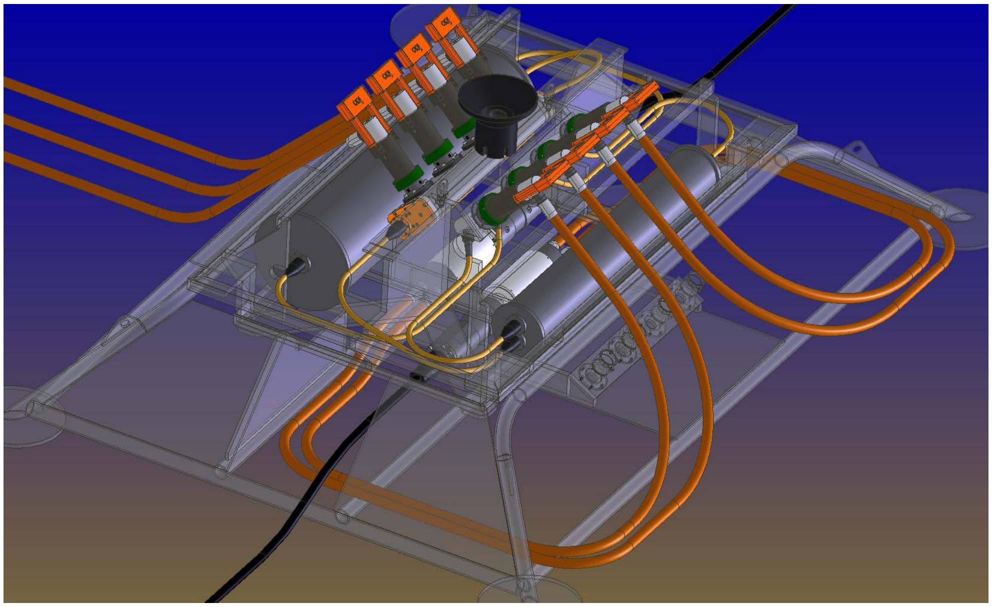

Figure 3

Engineering illustration of a Hub Node showing the electronics and optics pressure vessels. The trunk cable is in black. There are 3 cables with wet-mate connectors going to Sensor Nodes. The other connectors and cables allow the two pressure vessels to be disconnected form the Hub Node for repair or replacement. These elements are supported by an external frame which when covered will provide protection from external aggression.

In parallel with the shunt converters is transient suppression circuitry to protect the Hub Node (and adjacent Hubs) from large current and voltage transients caused by cable cuts or lightening. Calculations for a typical cable fault indicate that the resulting current transient will rise quickly (on the order of 10 μs) and experience a slower exponential decay. The half width of the initial transient is about 200 μs. In Figure 4 we show a calculated [1] plot of a current transient of a typical telecom cable 25 km from the actual fault. The observed peak current will depend, to first order, on the initial voltage and the capacitance and the group velocity of the cable as well as the distance from the fault. The plot in Figure 4 is representative of the temporal behavior one would observe for a current surge in most telecom cables that could be used as a trunk. Similar calculations have been used for some design inputs for the protection circuitry. The initial impulse is significant since it defines the fastest time scale the protection circuits must handle. This first and the subsequent peak set the energy scale of the transient which the protection circuits must handle. The 100 V output bus will have a current limiter built into it so that all the Sensor nodes plugged into this Hub Node bus are protected if one of the Sensor Node cables is accidentally shorted or disconnected.

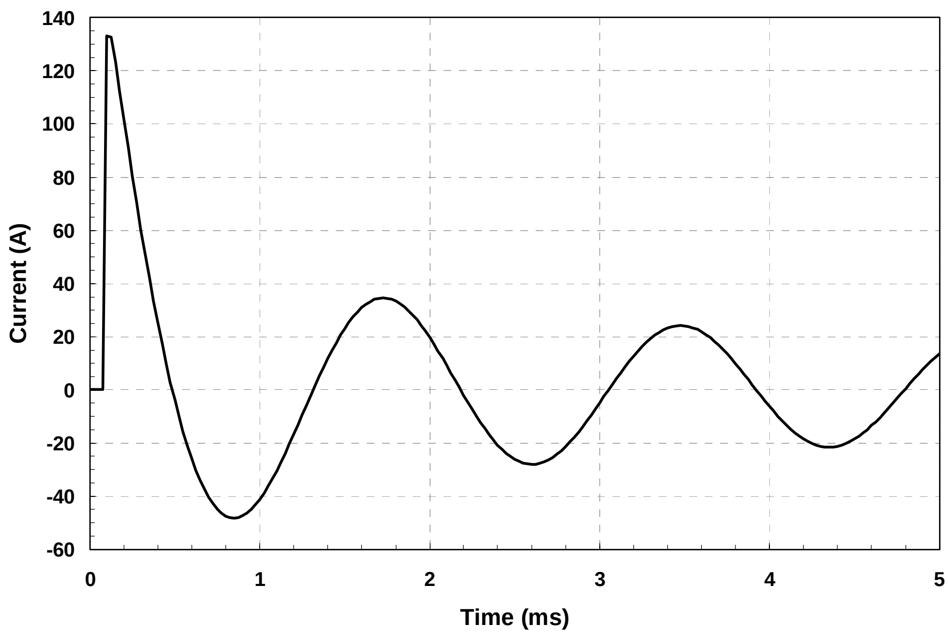

Figure 4

This shows the time evolution that is typical of a current surge caused by a cable cut. This calculation was done for a typical unarmored SL cable.

To facilitate communication from the sensors to the shore station, the Hub Nodes have optical wavelength add/drop multiplexers. These allow data to be sent to and from the Sensor Nodes. Each Sensor Node that is connected to the Hub Node will have access to a unique wavelength for bi-directional optical communication with the shore station. The trunk cable will carry all the wavelengths on a single fiber pair (plus a second, redundant, fiber pair with redundant signals as back up). One fiber in the pair carries traffic to the shore station from the sensors, the other fiber carries the traffic from the shore station to the sensors. All the wavelengths going in the same direction, will be multiplexed together on a single fiber in the trunk cable in a dense wavelength division multiplexing (DWDM) scheme using wavelengths chosen from the 100 GHz ITU grid. Since the ITU wavelengths are based on open standards optical transmitters, receivers and other components necessary for the communication path are readily available from many vendors and are known to be compatible. If all 11 Hub Nodes are used, the trunk cable will carry 33 wavelengths spanning a spectral width of 25.6 nm. This DWDM spectrum is easily accommodated by current undersea amplifier technology used in the telecom industry. Hence, if amplifiers are incorporated into the trunk cable, the reach of the trunk cable can be extended significantly. We believe 2000 km will be easily achievable, the ultimate reach will depend on the transponder quality, fiber choices and power available for the amplifiers. The second fiber pair in the trunk cable will serve as a redundant path for all data communications thus providing a very high degree of reliability for applications or missions with stringent reliability requirements.

The combination of the trunk cable and Hub Nodes forms the backbone of any sensor deployment and has been designed to be especially robust and reliable. High reliability components and redundant parallel configurations are used in the construction of the Hub Node to achieve the overall high reliability required to meet the lifetime target. This will ensure that a full deployment (Hub and Sensor Nodes) will perform for the target 20 year design lifetime with a 5 yr. mean time between operational failure (MTBOF).

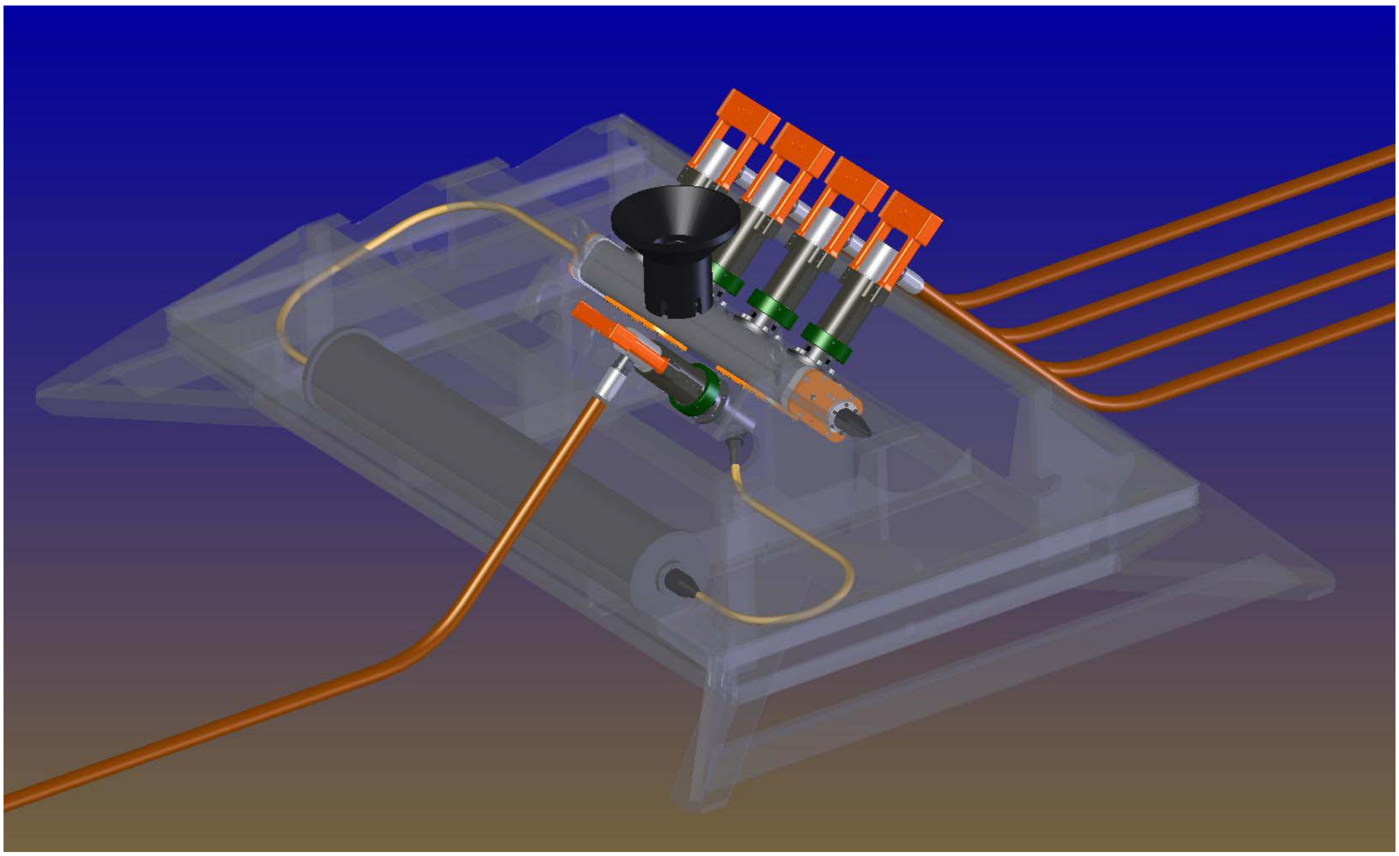

Figure 5

Conceptual Sensor Node drawing showing the use wet-mate connectors for connecting to 4 sensors as well as connecting to the Hub Node.

The Sensor Node

The Sensor Node serves as an electrical and optical interface to the sensors. The Sensor Node has four ports for connections with sensors, as shown in Figure 5. It takes the 100 V (less the cable loss) input from the Hub Node output port and converts it into the voltages required by the sensors connected to it. Typically this would be 48V, 12V, 5V and 3V (DC). The node will deliver 100 W of DC power for use by all four of the sensors. A survey of available data on oceanographic sensors indicates that 100W of power is adequate to support four such sensors (except for the high power lights). See Figure 6. For significantly higher power requirements, a high power Sensor Node has been designed that will take the full power output of a Hub Node and deliver 470 W of useable power to a single sensor port. This will be useful for, charging ROVs and AUVs, powering video installations requiring high power lighting as well as powering a large sensor array. As with the Hub Node, the Sensor Node incorporates high reliability parts and uses redundant configurations to achieve and overall high reliability.

For connecting to the sensors the Sensor Node will be able to support a variety of standard instrument interfaces including RS232/422 and RS485. There will also be an optical interface for instruments (or arrays) that output optical data. The Sensor Node will have a microprocessor to manage the functions of the node. This includes turning on and off of sensors, managing the communication to and from the individual sensors and, if needed, A/D conversion of incoming data. The microprocessor is also a communication interface between the Sensor Node and the shore station via its connection to an optical transmitter and receiver. The microprocessor will multiplex (in the electrical domain) signals from all the sensors. This electrical data stream will then be used to drive an optical transmitter that is connected to one fiber in the bi-directional fiber pair. The optical transmitter sends data to the shore station on a single dedicated wavelength. The microprocessor will also be connected to an optical receiver that terminates the other fiber in the bi-directional fiber pair. It can receive data from the shore station via the same wavelength which is used on the outbound data. The optical transmission format can be either GigE, OC3 or OC12 which are all standard formats. The microprocessor will use an open software architecture to allow users to develop their own drivers to interface to unsupported sensors. It will also use an XML schema for the data output.

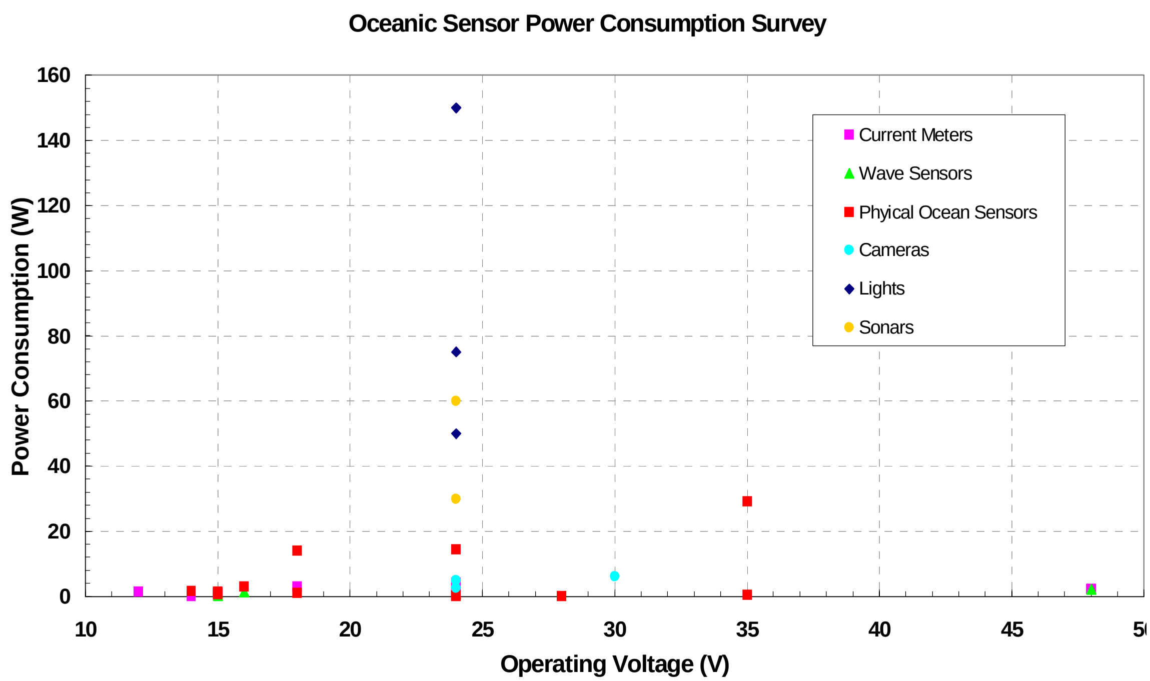

Figure 6

Plot of the survey results of the power consumption for available oceanographic sensors. From this we can see that each Sensor Node can support all but the highest power lights.

Additional features of the microprocessor will support security at admin and data access levels, timing for sensor data collection, and meta data tagging. The data output would be commanded at the shore station with a web server and allow other users access to the data via a web browser.

The Hub Nodes are connected to the Sensor Nodes by a cable carrying two conductors and two bidirectional fiber pairs. The Sensor Nodes can be placed up to 4.5 km from the Hub Nodes, depending on the impedance of the connecting cable. The cable connecting the Hub Node to the Sensor Node will have wet mate connectors at each end. This will allow the Sensor Node to be easily removed for repairs, relocation or upgrades. The Sensor Node can be removed without interrupting the flow of power or data traffic to other Hubs or Sensor Nodes. It also allows for a less complex initial installation; the sensor Node can be put in place and then connected to the Hub. The connection can be made by a diver or ROV. The individual sensors will connect to the Sensor Node with wet mate connectors. This will allow individual sensors to be replaced, if they are broken, or as the research goals evolve.

Shore Station

The shore station will terminate the trunk cable optically and electrically. The shore station will contain a 10 kW constant current DC power supply to power the trunk cable which determines the maximum amount of power that can be supplied to an installation of sensors. This will be a standard commercially available telecom PFE.

The shore station will also contain terminations for each of the two bidirectional fiber pairs in the cable. The inbound fibers will be connected to an optical demultiplexer which separates the incoming DWDM wavelengths out onto separate fibers. These are then connected to the receive port on the corresponding transponder. Signals from the transmit port of the transponders will be combined onto a single fiber using an optical multiplexer and then launched onto the cable. In this way each Sensor Node, corresponding to a unique wavelength, will be connected to a specific transponder. The transponders are then connected to a router that disaggregates data from individual sensors that are multiplexed on each wavelength. This router allows individual sensor data to be routed to a specific end user. The switch can be configured to allow individual end users two-way communication with specific sensors and allow them tailored access to specific sensors and their data output.

Conclusion

The Gateway system modules can be used to construct undersea sensor arrays to suit a wide variety of applications. The system is modular by design for ease of deployment, maintainability, and expandability. It is designed to minimize total installed cost and total life cycle cost. The modules will support most common sensor interfaces as well as communication formats and protocols making it easy for designers and users to work with. The use of wet mate connectors at the appropriate interfaces (sensors and sensor nodes) will allow existing and future deployments of sensors to be configured and reconfigured as the users needs evolve. The wet-mate connectors come in several configurations electrical, optical, electro-optic and high power. This allows you greater flexibility in the system design.

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Footnotes

[1] This plot reprinted with the permission of Dr. S. A. H. Smith of Kabculus. Personal communication.